Dynamic Scattering of Coherent Soft X Rays

Laser-Like X Rays Illuminate Fast Fluctuations in Molecules

The laser revolutionized experimental science by providing a source of coherent light. For example, light-scattering experiments using coherent visible-wavelength light allow the detailed measurement of dynamic microscopic phenomena such as the Brownian motion of small particles. However, an analogous technique for studying motion on a much smaller, molecular scale requires shorter-wavelength coherent light in the soft x-ray range (10 to 100 Å), which lasers cannot supply. To study thermally driven fluctuations inside molecules, a group of scientists at the ALS has applied coherent soft x rays from Beamline 7.0.1.3 to dynamic scattering experiments on liquid-crystal films.

Recently, there has been considerable interest in using hard x rays (at wavelengths near 1 Å) to probe relatively slow (tenths of a second to hours) atomic-scale motions. Because the motions are slow, fewer coherent photons are needed to accurately measure the fluctuations. However, the measurement of fast (microsecond) molecular-scale motion requires more coherent photons than can be obtained at a third-generation hard x-ray synchrotron.

Fortunately, the available coherent flux of an x-ray source (hard or soft) is proportional to the wavelength of the light squared; in other words, the longer the wavelength, the higher the coherent flux. Therefore, one can get 2000 times more coherent photons using 44-Å soft x rays than from using 1-Å hard x-rays. Because the researchers were interested in fluctuations at the molecular rather than atomic level, they could afford to use longer wavelengths. At Beamline 7.0.1.3, a double-pinhole coherence filter converted the low-coherence raw undulator beam into a high-coherence incident beam. With this setup, the researchers were able to achieve the same time resolution as with conventional laser-light scattering (about 1 μs) and 100 times better spatial resolution (44 Å vs. 6360 Å).

The goal is to develop this technique so that it can be used to probe fluctuations during phase transitions and to study the internal motions of biological molecules that are thought to be crucial to chemical reaction rates, catalysis, and biological function. Before applying the technique to the difficult problems of phase transitions and biology, however, the researchers decided to apply it to a simpler problem: measuring the layer fluctuations of freely suspended liquid-crystal films.

The liquid-crystal films used in this experiment were heated to the smectic-*A* transition point. In the smectic-*A* phase, the layers of the crystal can “slide” back and forth and the molecules are free to move within the layers. When photons are reflected from this fluctuating system, the intensity of the reflected beam will fluctuate because of the fluctuations of the sample. If the incident beam is spatially coherent, the reflected-beam fluctuations are an average over all of the illuminated molecules. By fitting the normalized reflected-beam intensity to an exponential curve, the researchers determined the characteristic decay time of the layer fluctuations for five types of liquid crystals. A plot of decay time vs. film thickness for each of the five types of crystal studied shows obvious linearity, in excellent agreement with the predictions of theoretical models.

With future access to the raw undulator beam on the new Beamline 9.0.1 (unfiltered by a monochromator and not subject to losses from passing through optical components), the available coherent flux will increase by 1000. Once suitable technique and source improvements are made, researchers should be able to go beyond the usual time-averaged x-ray snapshots to produce x-ray movies of the motion of molecules and atoms.

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A. C. Price, L. B. Sorensen, S. D. Kevan, J. Toner, A. Poniewierski, and R. Holyst, “Coherent Soft-X-Ray Dynamic Light Scattering from Smectic-*A* Films,” *Phys. Rev. Lett.* **82** (1999) 755.

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DYNAMIC SCATTERING OF COHERENT SOFT X RAYS

Laser-Like X Rays Illuminate Fast Fluctuations in Molecules

- **Technique combines advantages of lasers and soft x rays**
  - *Lasers: coherence*
  - *Soft x rays: probe molecular-scale phenomena*
- **Goal: study fast fluctuations inside molecules**
  - *Fluctuations during phase transitions*
  - *Internal motions of biological molecules*
- **First step: measure layer fluctuations in liquid-crystal films**
  - *Layers can slide back and forth, molecules move freely within layers*
  - *Measured characteristic fluctuation decay times*
  - *Results in excellent agreement with theoretical models*
- **Future improvements in technique**
  - *Use unfiltered undulator beam at new beamline*
  - *Improve coherent flux by 1000*
  - *Produce x-ray movies of molecular motion*

A.C. Price and L.B. Sorensen (University of Washington, Seattle); S.D. Kevan and J. Toner (University of Oregon); and A. Poniewierski and R. Holyst (Polish Academy of Sciences, Warsaw). **[*Phys. Rev. Lett.* 82 (1999) 755]**

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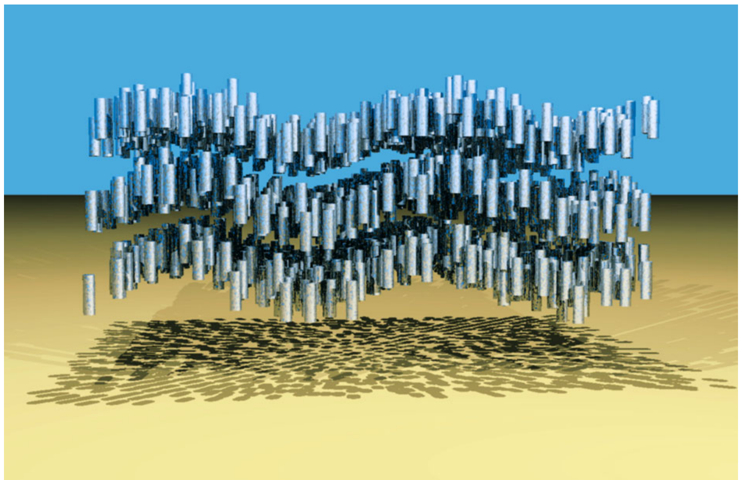
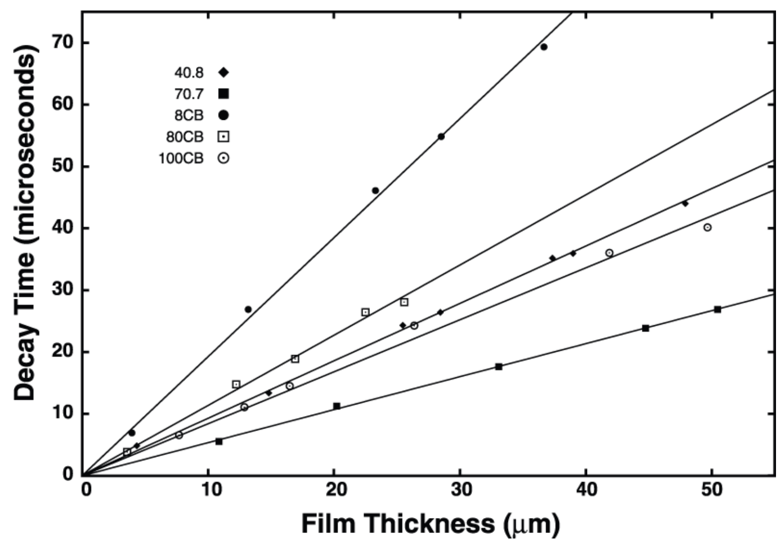


Artist's illustration of the layer fluctuations in a liquid crystal film. The separations between the molecules and between the layers have been exaggerated (illustration by Dennis Yee).



Decay time vs. film thickness for five types of liquid crystals. The straight lines are fits to theoretical predictions.

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